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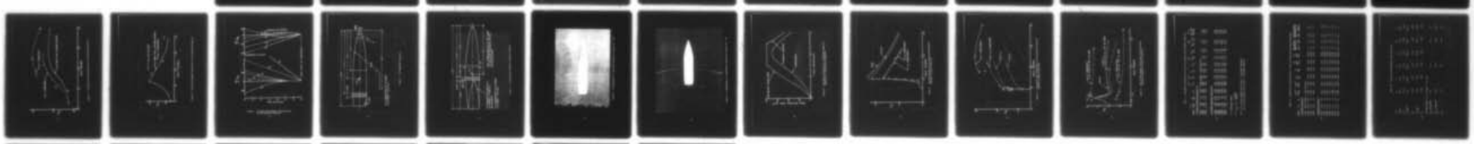

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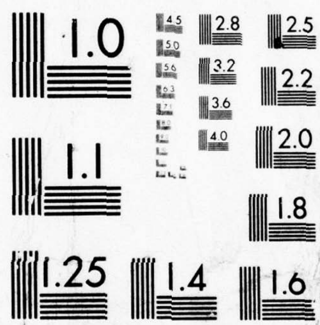

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MEMORANDUM REPORT ARBRL-MR-02825

(Supersedes IMR No. 541)

AEROBALLISTICS OF CORKSCREW PROJECTILES

Anders S. Platou

April 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (lcb)

Preliminary wind tunnel and aeroballistic range tests on a new and novel exterior projectile shape have shown that this 5-caliber to 8-caliber long shape has extremely good aerodynamic characteristics. It not only has very low drag, but also low pitching and Magnus moments which in turn yield good gyroscopic and good dynamic stability. Extrapolation of the data to longer lengths indicates that 10-caliber to 12-caliber long projectiles having this shape can be flown with satisfactory stability.

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I. INTRODUCTION

During the development and exploitation of the BRL Non-Conical Boattail Projectile[1-6], it became evident that a new projectile shape which combines a triangular nose with a triangular boattail (Figure 1) would have low drag and a long wheel base for low balloting in the gun barrel. No aerodynamic data were available on the configuration (nicknamed the corkscrew) at the beginning of this program, so it was deemed advisable to conduct wind tunnel and range tests to determine its drag and stability characteristics.

II. THE CORKSCREW GEOMETRY

The basic corkscrew geometric pattern is obtained by cutting a solid cylinder with six skewed planes to obtain the configuration shown in Figure 1. Three skewed planes form the pointed triangular nose and the other three skewed planes, sloped the opposite way, form the boattail. The boattail planes up to now have been terminated when they form an inscribed triangle, but it is possible to terminate them at any desired axial station. The slope or angle of these planes with respect to the cylinder centerline can be varied; however, the angles of the three nose planes must be the same as well as the angles of the

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1. *Anders S. Platou, "An Improved Projectile Boattail," Ballistic Research Laboratory Memorandum Report No. 2395, July 1974. AD 785520.*

2. *Anders S. Platou and George I. T. Nielsen, "An Improved Projectile Boattail. Part II," Ballistic Research Laboratory Report No. 1866, March 1976. AD A024073.*

3. *Anders S. Platou, "An Improved Projectile Boattail. Part III," Ballistic Research Laboratory Memorandum Report No. 2644, July 1976. AD B012781L.*

4. *John H. Whiteside, "Transonic Tests of the 155mm Non-Conical Boattail Projectile A and 8-Inch XM650E4 and EBVP Projectiles at Nicolet, Canada, During January-February 1977," Ballistic Research Laboratory Memorandum Report No. ARBRL-MR-02809, January 1978.*

5. *Vural Oskay and Anders S. Platou, "Yawsonde Tests of 155mm M549 Non-Conical Boattail Projectile at Tonopah Test Range," Ballistic Research Laboratory Memorandum Report in preparation.*

6. *Anders S. Platou, "Wind Tunnel, Aeroballistic Range, and Full Range Flight Tests of the Non-Conical Boattail Projectile A," Ballistic Research Laboratory Memorandum Report in preparation.*

three boattail planes. The nose plane angles need not be the same as the boattail plane angles. The six planes are usually skewed at a constant twist rate generally near the spin expected at launch.

The corkscrew configuration does not have the usual axial symmetry and, therefore, it can be expected to have non-linear aerodynamic characteristics, especially at spins (pd/V) far from the configuration twist. For this reason, the spin of all of the range flights made to date have been near the twist of the configuration.

III. TEST RESULTS

The first data came from supersonic wind tunnel tests of a 5-caliber long non-interdigitated or non-overlapping configuration (Figure 2). This configuration has a 10° nose angle and a 7° boattail and the model is 5.715 cm in diameter. The significant results from these tests are described below and are compared with results from the 5-caliber Army-Navy Spinner Rocket (ANSR) with a cylindrical tail.

(a) Even though the normal force on the corkscrew is extremely high (Figure 3), the pitching moments about a center of gravity three calibers aft of the nose are about the same as those on the 5-caliber ANSR (Figure 4). Therefore, the normal force center of pressure of the corkscrew configuration is located further aft than on the 5-caliber ANSR.

(b) At low angles of attack, the Magnus forces and moments are *small at all spin rates near the configuration twist.* This is due to the zero-spin "offsetting" side force and moment characteristic of this configuration[2] (Figure 5).

Because of the difficulty in designing and building the interdigitated wind tunnel version, 20 mm diameter 6-caliber and 8-caliber long models were built for flights in the BRL Aerodynamics Range. The models were made of brass and used drilled base holes to increase the possibility of stable flights in the range. The 6-caliber long models had 7° triangular boattails and 5.71° triangular noses while the 8-caliber long models had 4.76° on both nose and boattail planes. Both the 6-caliber and 8-caliber configurations had one caliber overlap between the nose and boattail planes. Below, aerodynamic data from several flights up to M = 2.2 are compared with aerodynamic data on the 5.7-caliber long M549 (Figure 6) and the 6.2-caliber long non-conical boattail projectile-A (Figure 7).

(1) Shock waves or flow discontinuities on the corkscrew configuration appear to be virtually non-existent at transonic speeds (Figure 8). This figure can be compared to the shock wave pattern existing on a conventional projectile configuration at the same Mach number (Figure 9). The almost shock-free flow pattern is believed to be due to the

more uniform area distribution of the corkscrew configuration (Figure 10). Further studies in both ranges and wind tunnels would be necessary to completely understand and explain this phenomenon.

(2) The drag coefficient of the corkscrew configuration is very low compared to that of the two reference projectiles (Figure 11).

(3) The normal force coefficient (Figure 12) is not as large as for the non-interdigitated wind tunnel configuration, but it is larger than for the M549 and the NCB-A projectiles.

(4) Even with the rearward center of gravity of the corkscrews, the pitching moment coefficient is much lower for the 6-caliber corkscrew (Figure 13) than for the M549 and NCB-A projectiles. The pitching moment coefficient of the 8-caliber corkscrew is just slightly higher than the maximum pitching moment coefficient of the M549. The pitching moment coefficient of the corkscrew appears to remain nearly constant with Mach number, indicating that the corkscrew configuration does not have the characteristic spike in the pitching moment curve. Additional data above $M = 1.05$ are required to verify this.

(5) Efforts to fly corkscrews at higher Mach numbers have so far failed due to excessive loads on the model nose during launch. Various launching techniques are being tried to overcome this problem.

(6) The aerodynamic and aeroballistic coefficients of the corkscrew configurations obtained from the various flights are given in Tables I and II.

IV. EXTRAPOLATION TO LONGER LENGTH PROJECTILES

The aerodynamic data obtained on the corkscrew configurations indicate that longer configurations of this shape can be flown with satisfactory stability. The implication is that the corkscrew will permit the use of much longer, full bore, spin-stabilized, low drag projectiles.

Calculation of possible projectile lengths have been made and the results are shown in Table III. For the calculation of the moments of inertia, it was assumed that the corkscrew configuration has equal angles for the nose and tail "flats", that the nose and tail overlap by one caliber, and that the projectile is made of a homogeneous material with a density of 9 g/cm^3. Using the obtained values for the 6-caliber and 8-caliber corkscrews, the normal force and pitching moment coefficients for longer configurations have been estimated at Mach 2.1 (Table III).

From these assumptions and calculations, the gyroscopic stability factor has been calculated. This calculation indicates that an 11-caliber corkscrew made of homogeneous material with a density of 9 g/cm^3 can be flown with satisfactory stability if the spin is at least one revolution per fifteen calibers of forward travel.

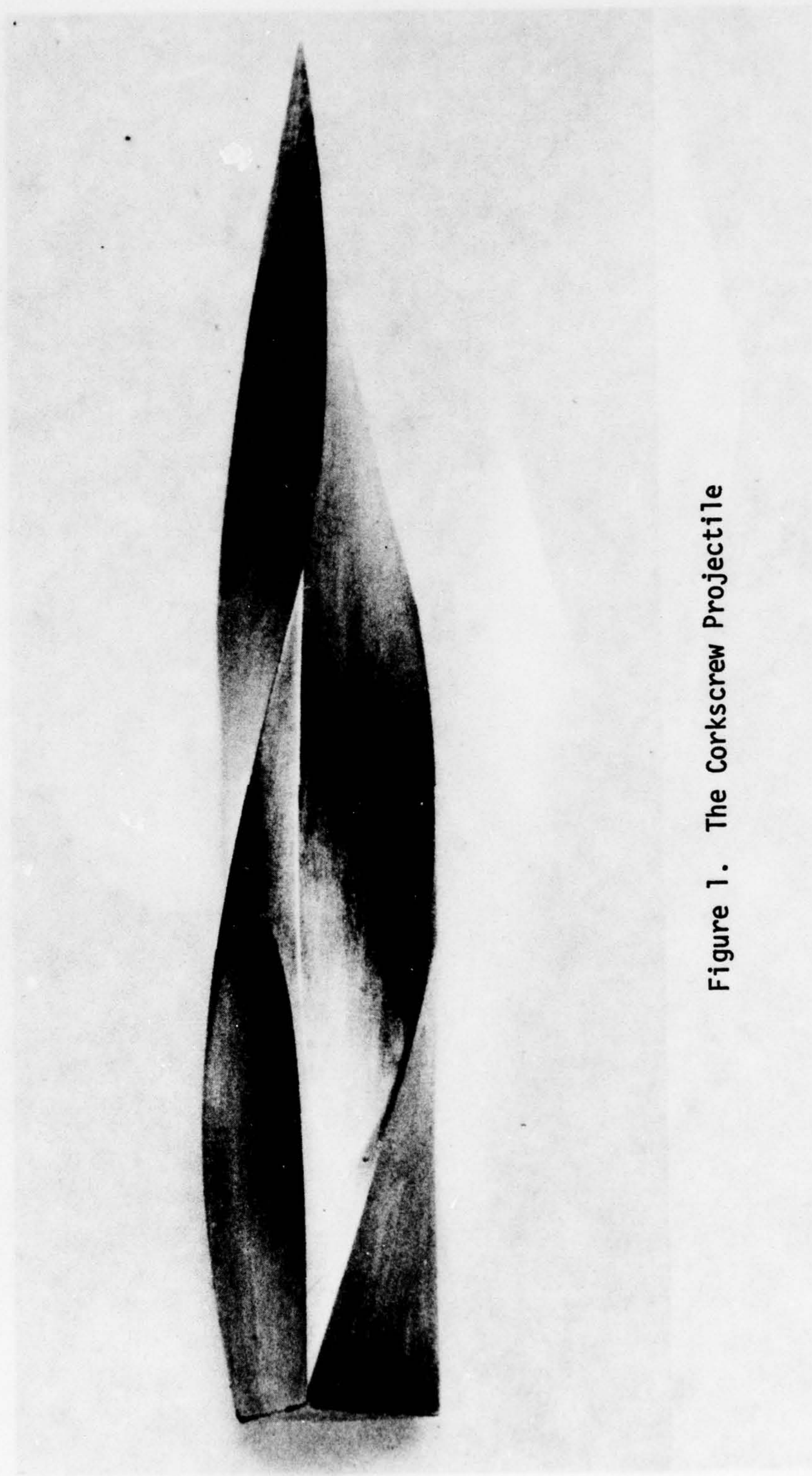

Figure 1. The Corkscrew Projectile

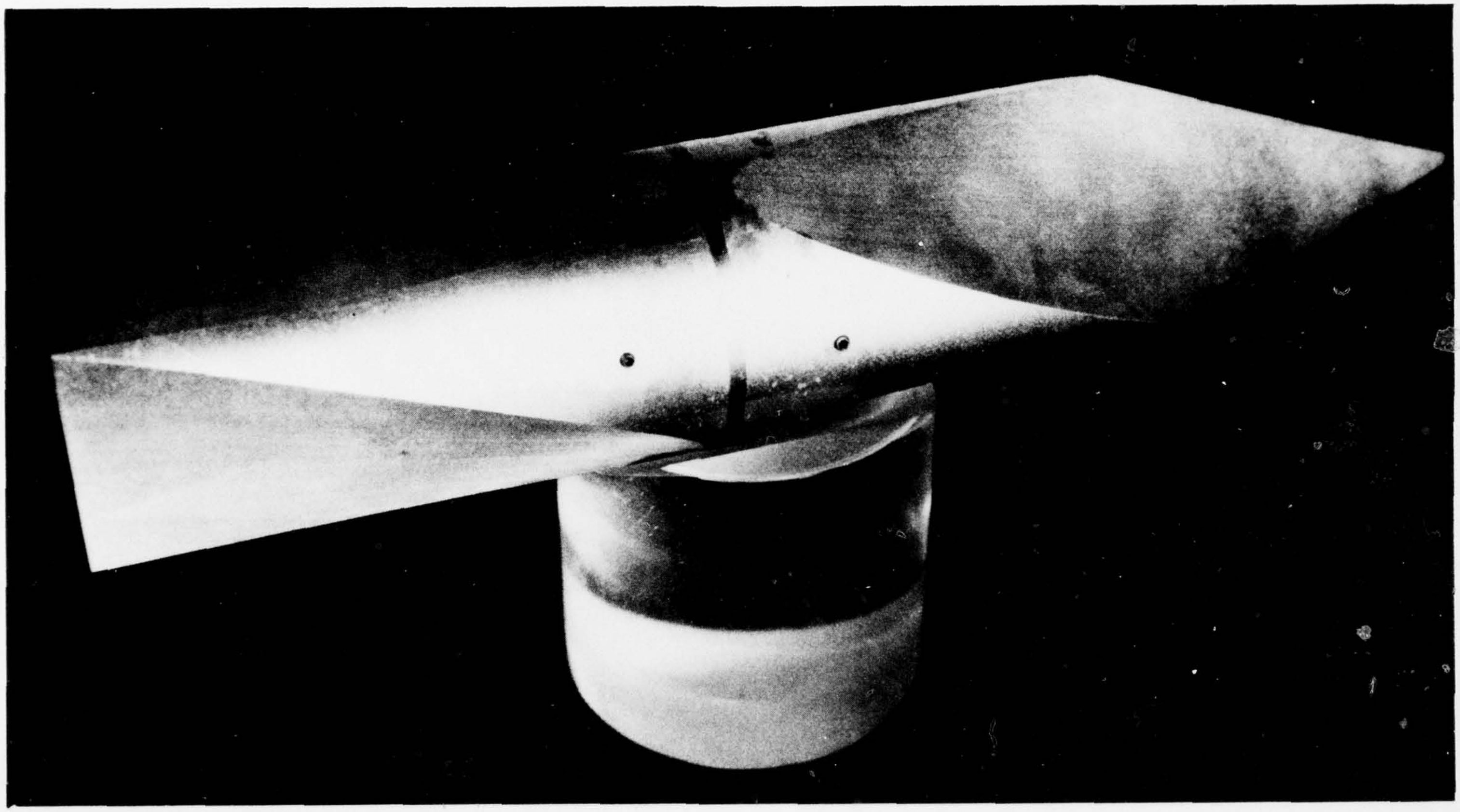

Figure 2. The 5-Caliber Wind Tunnel Model of the Corkscrew Projectile

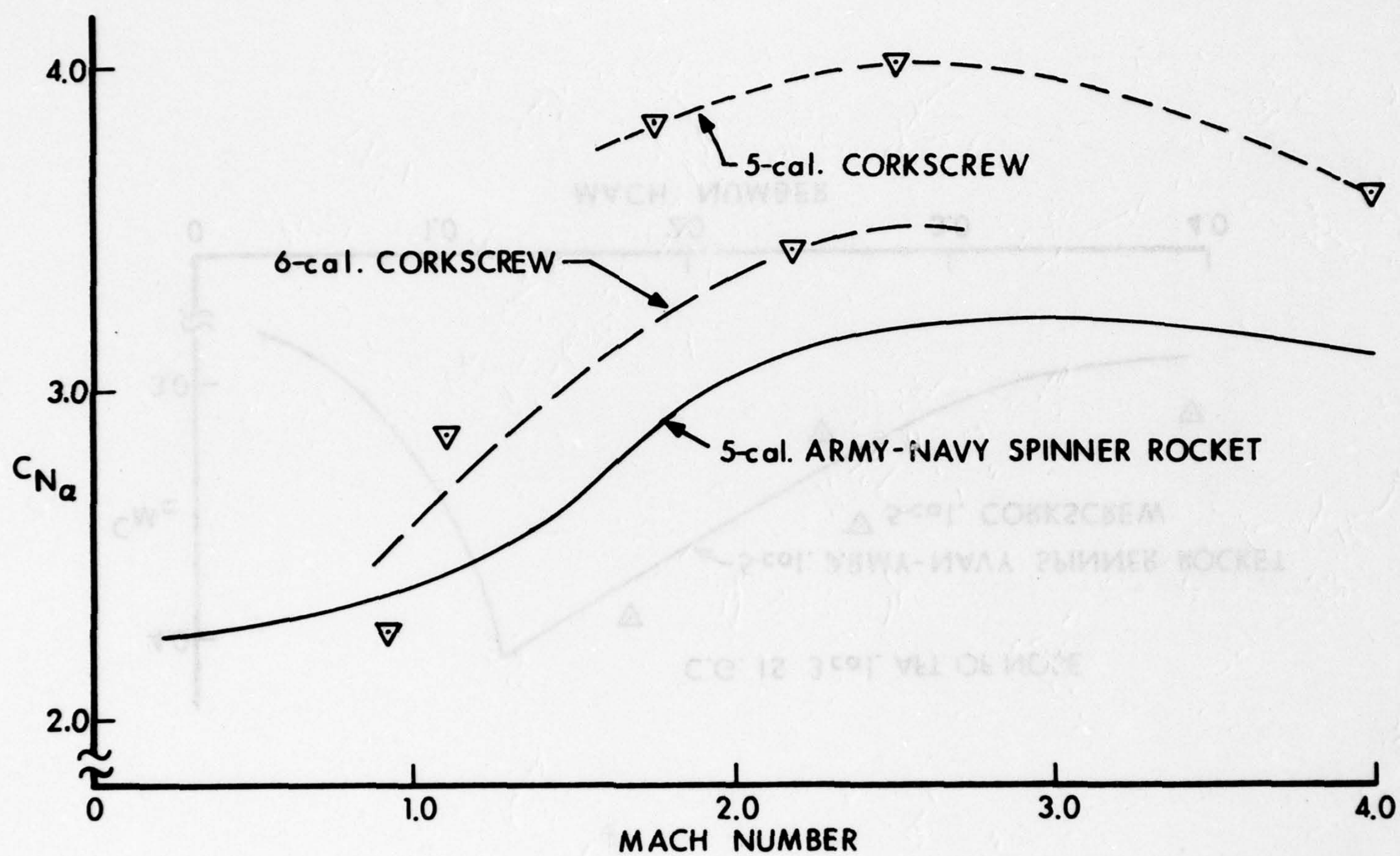

Figure 3. The Normal Force Coefficient of the Corkscrew Projectile

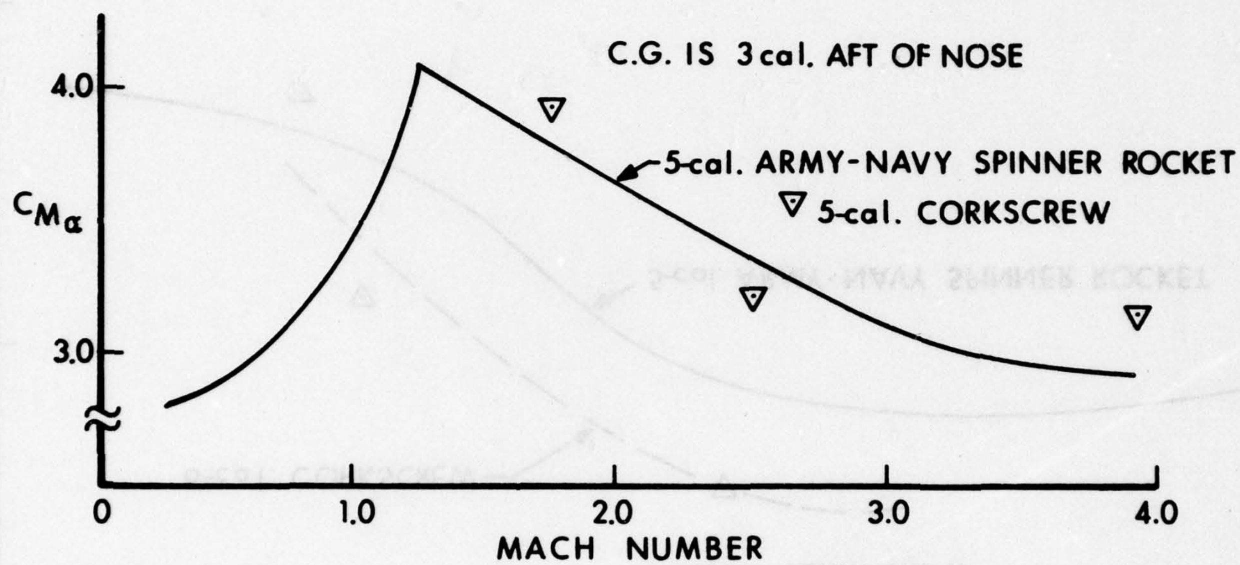

Figure 4. The Pitching Moment Coefficient of the Corkscrew Projectile

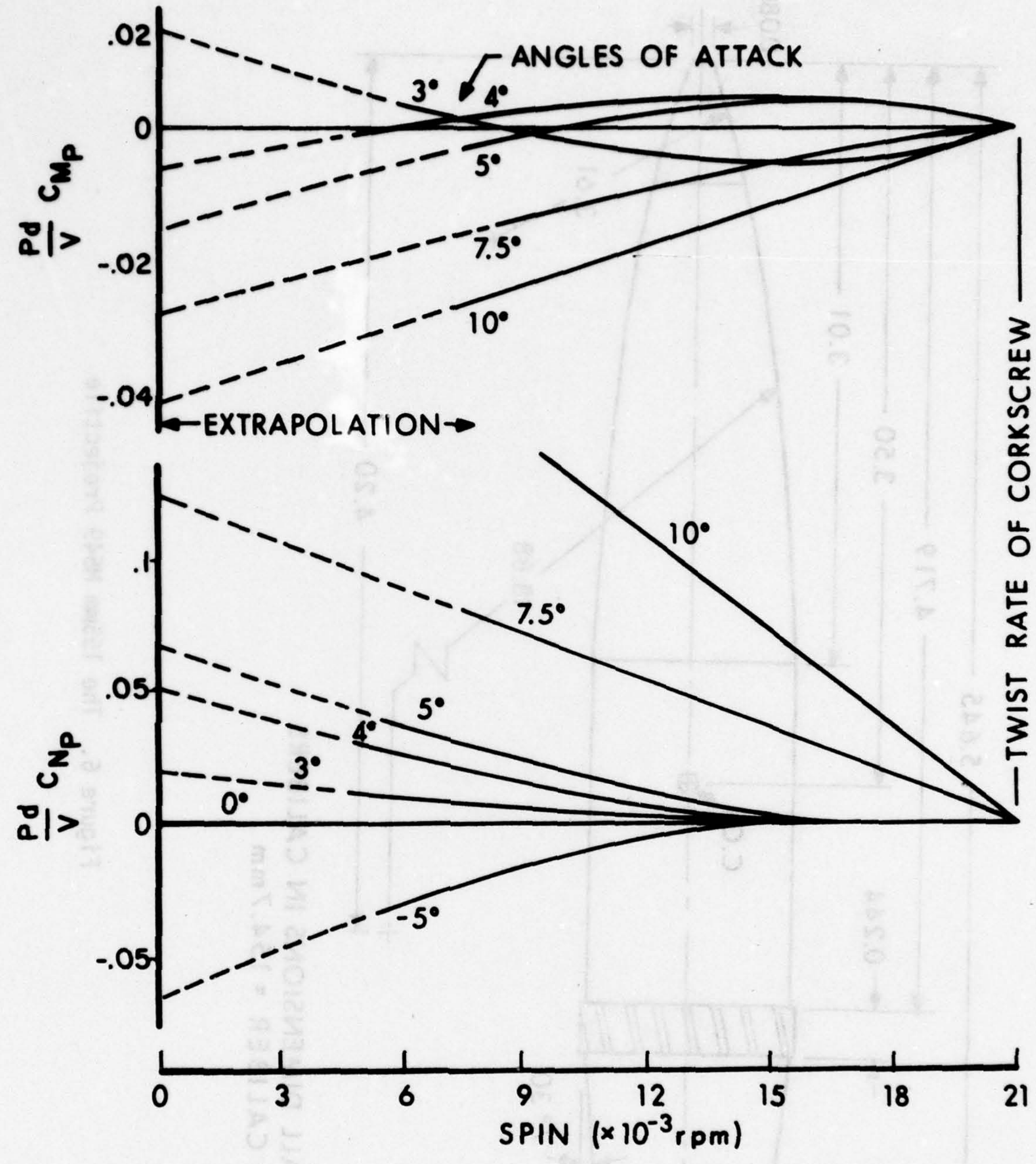

Figure 5. The Approximate Magnus Characteristics of the Corkscrew Projectile

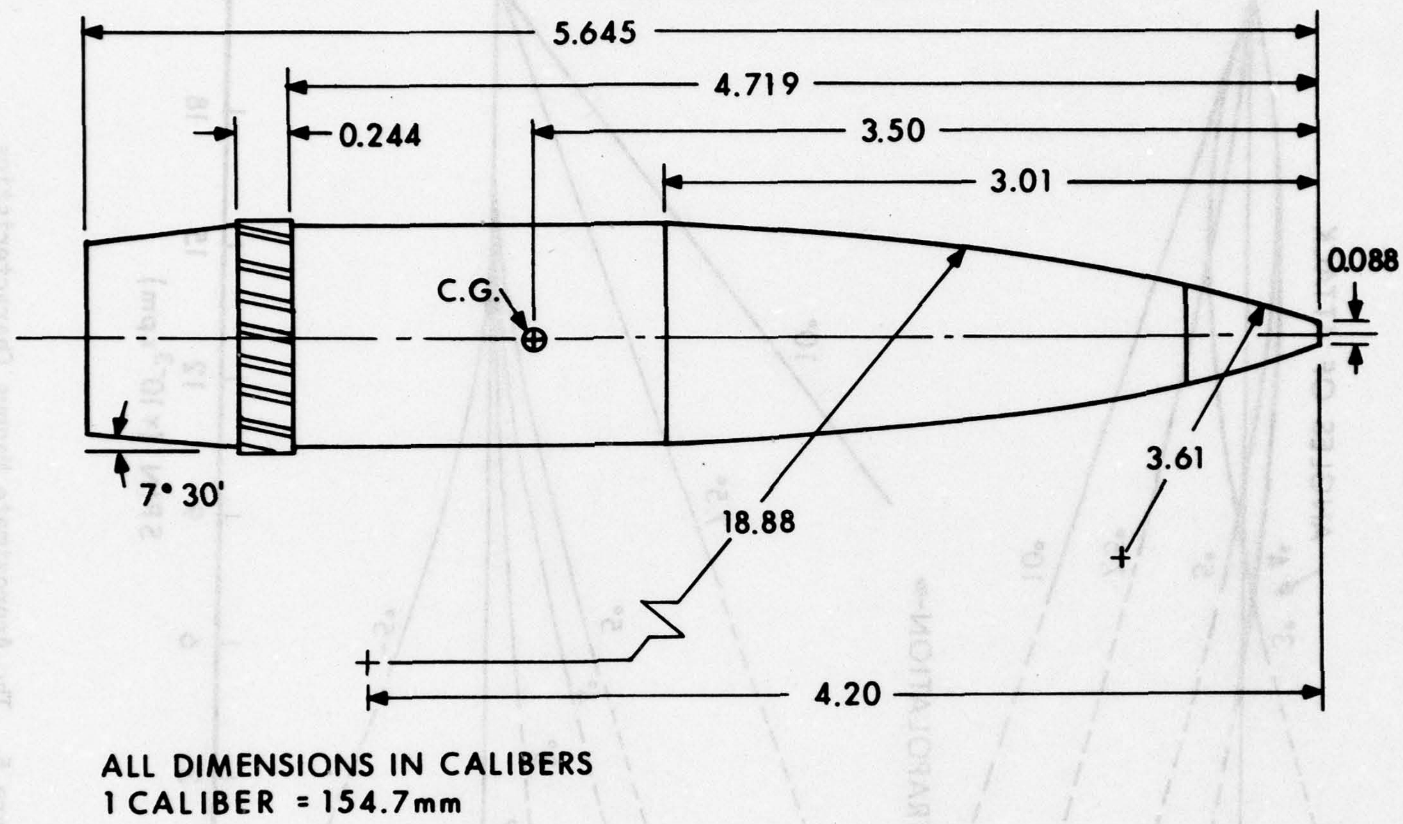

Figure 6. The 155mm M549 Projectile

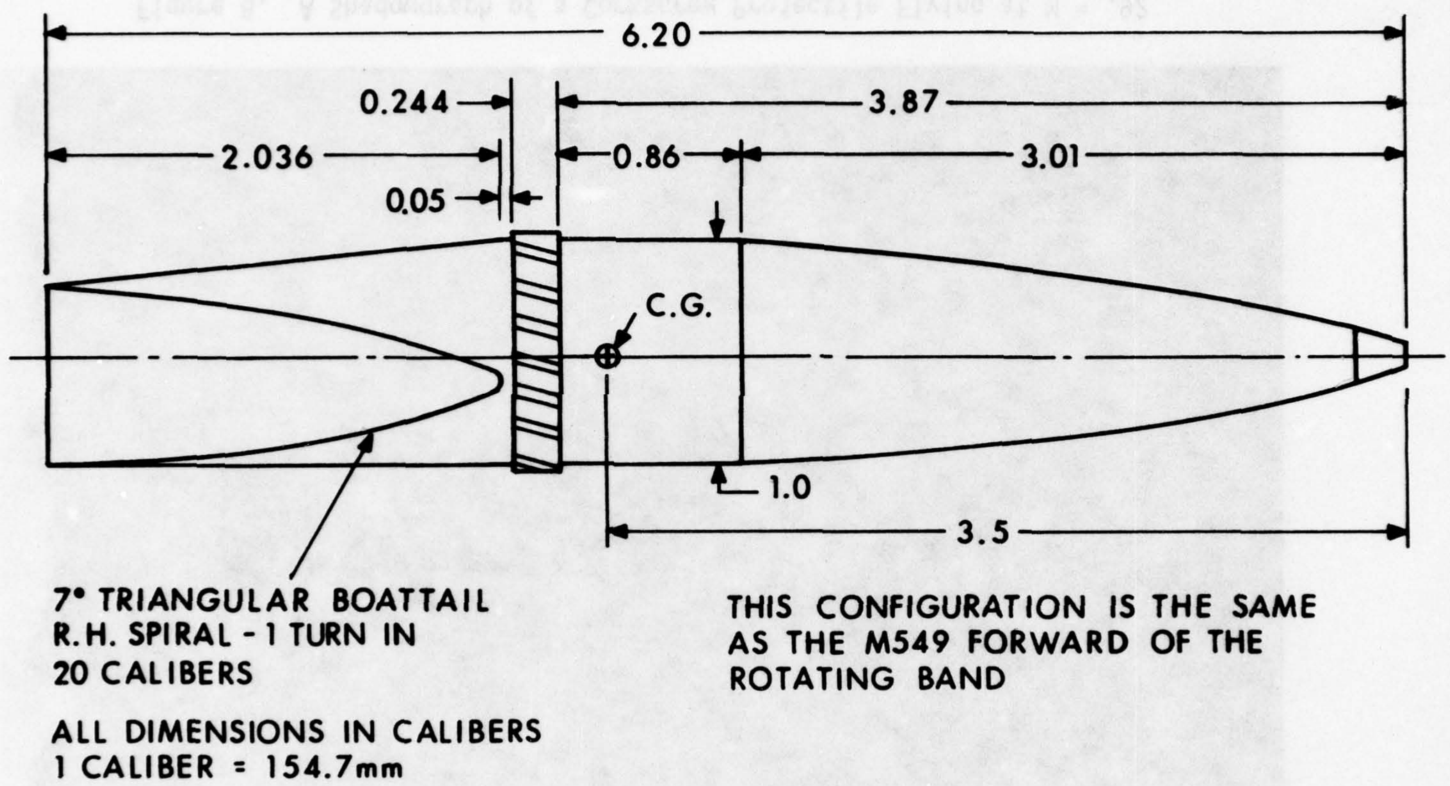

Figure 7. The Non-Conical Boattail Projectile (NCB-A)

Figure 8. A Shadowgraph of a Corkscrew Projectile Flying at M = .92

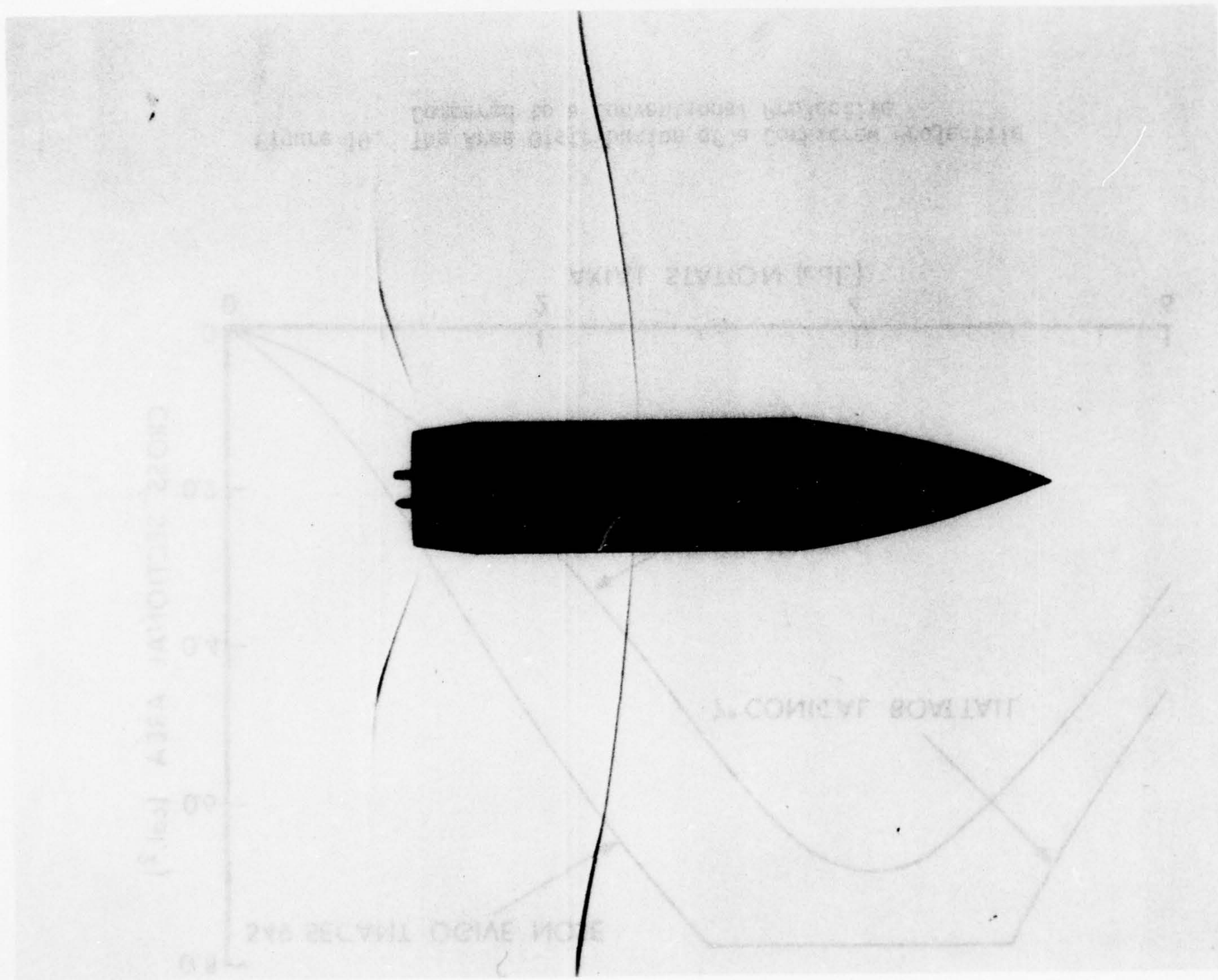

Figure 9. A Shadowgraph of a Conventional Projectile Flying at M = .92

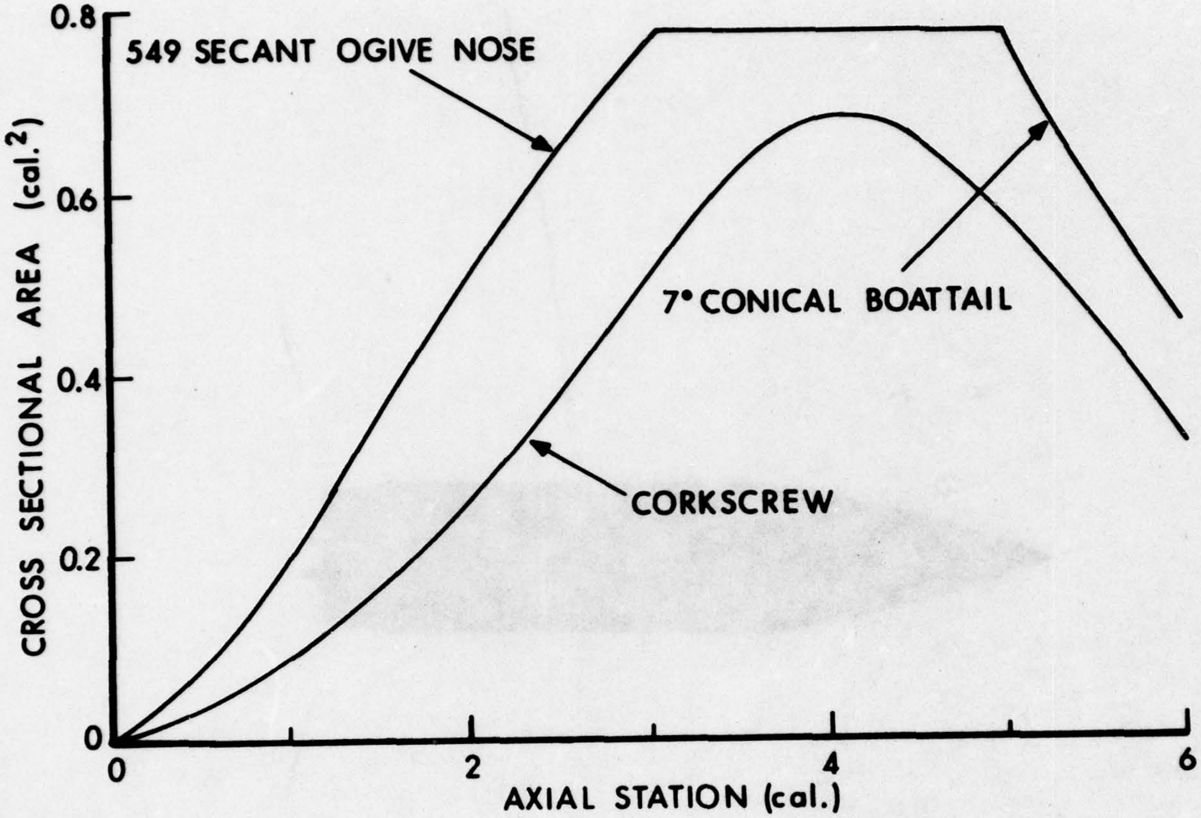

Figure 10. The Area Distribution of a Corkscrew Projectile Compared to a Conventional Projectile

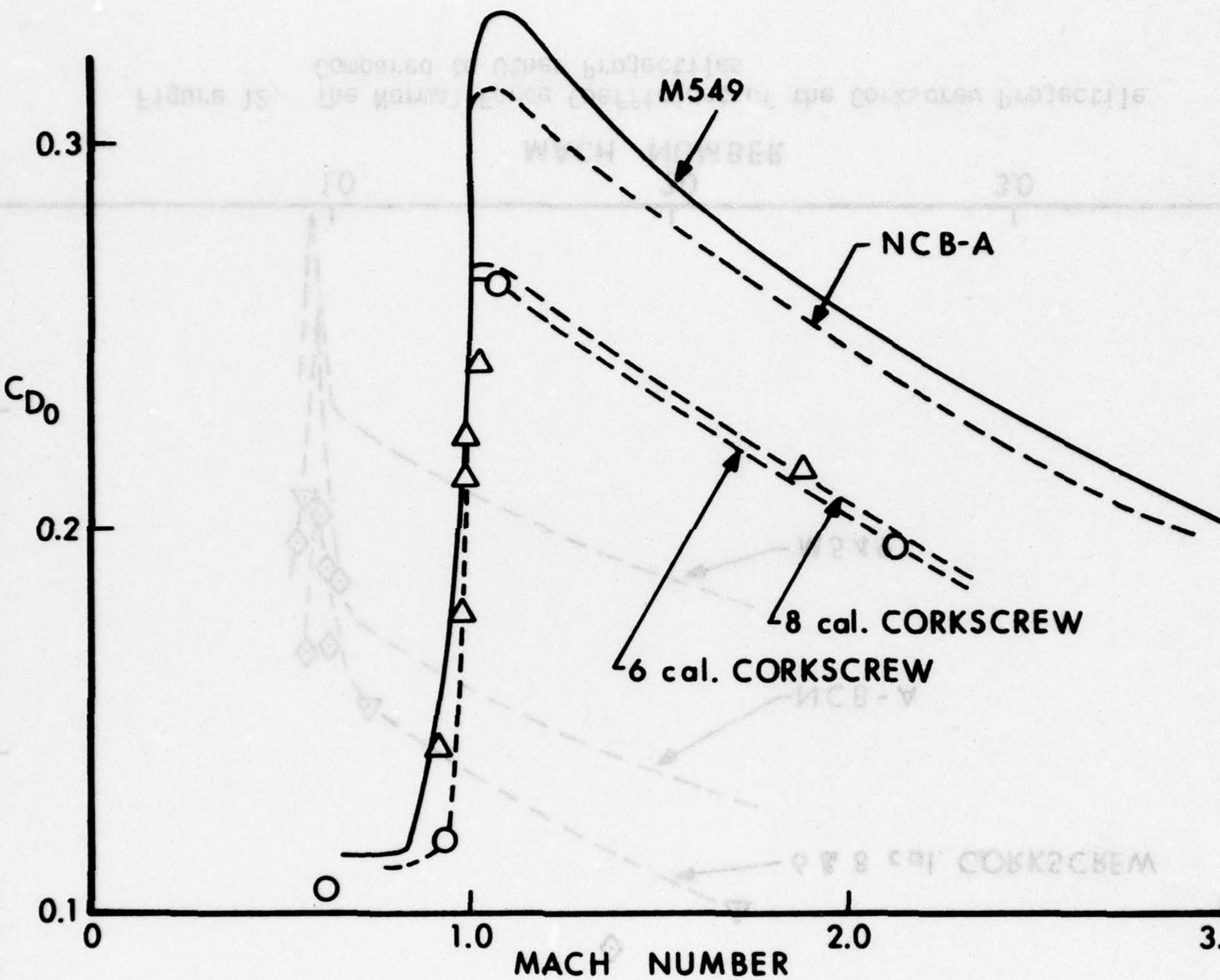

Figure 11. The Drag Coefficient of a Corkscrew Projectile Compared to Other Projectiles

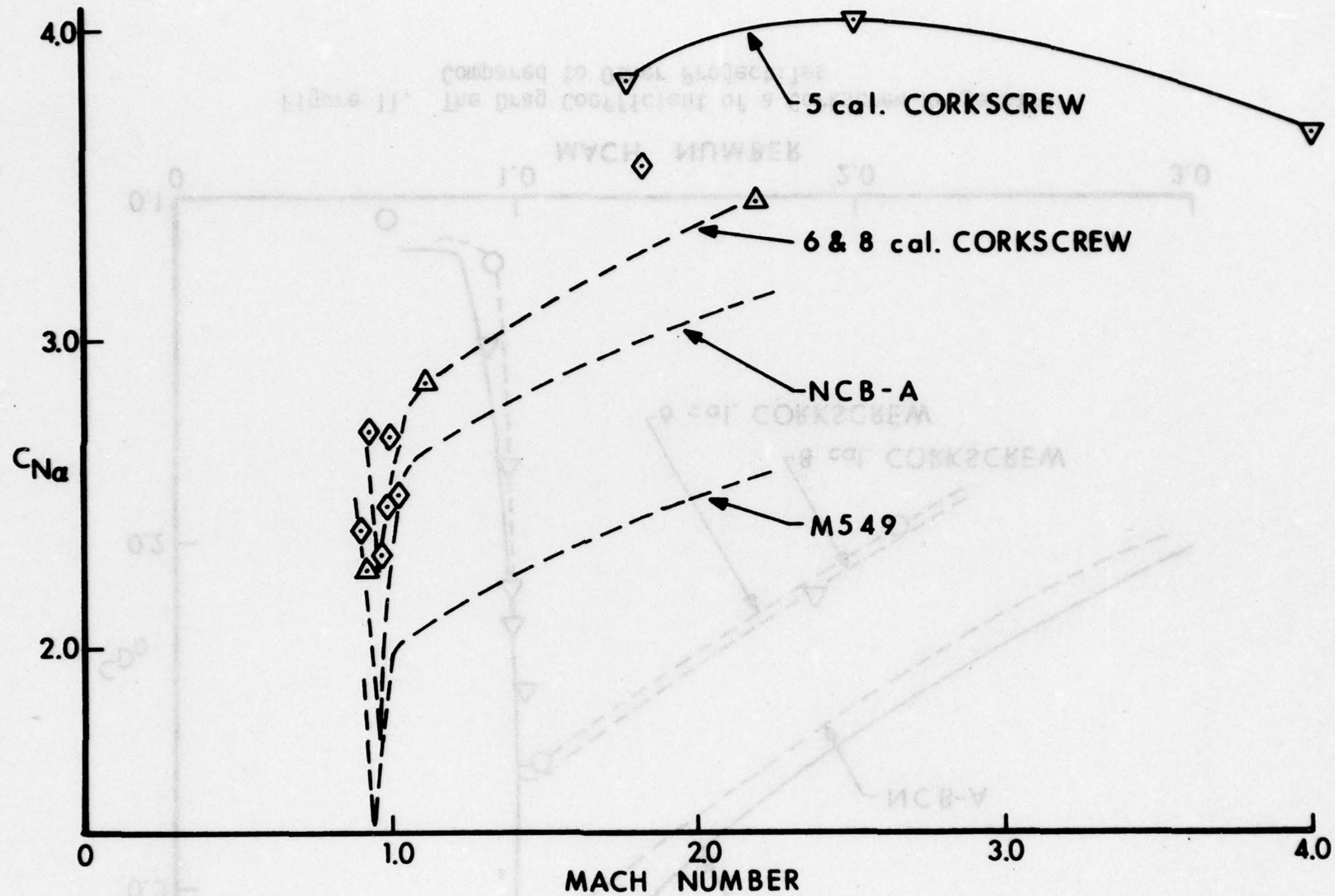

Figure 12. The Normal Force Coefficient of the Corkscrew Projectile Compared to Other Projectiles

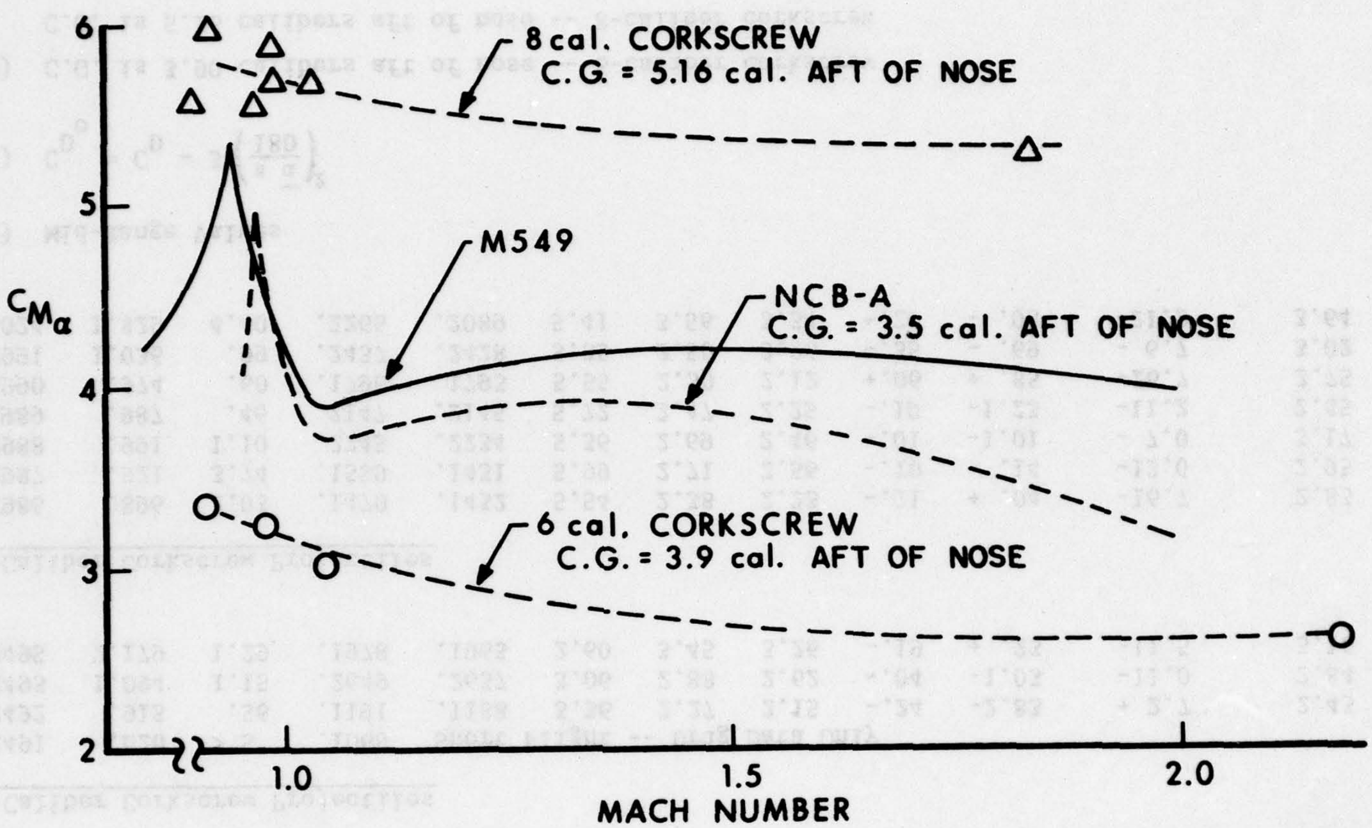

Figure 13. The Pitching Moment Coefficient of the Corkscrew Projectile Compared to Other Projectiles

Table I. Aerodynamic Characteristics of the 6-Caliber and 8-Caliber Corkscrews

Round	(1) Mach	$\bar{\alpha}$ Deg.	C_D	(2) C_{D_o}	(3) C_{M_α}	C_{N_α}	C_{L_α}	(3) $C_{M_{p\alpha}}$	$C_{N_{p\alpha}}$	(3) $C_{M_q} + C_{M_{\dot{\alpha}}}$	$C.P._N$ Cal. Aft of Nose
6-Caliber Corkscrew Projectiles											
12491	.620	> 5°	.1068	Short Flight -- Drag Data Only							
12492	.913	.56	.1191	.1188	3.36	2.27	2.15	-.24	-2.83	+ 2.7	2.43
12493	1.094	1.15	.2649	.2637	3.06	2.88	2.62	-.04	-1.03	-11.0	2.84
12495	2.179	1.29	.1978	.1963	2.60	3.45	3.26	-.19	+ .23	-11.5	3.16
8-Caliber Corkscrew Projectiles											
12986	.896	2.03	.1470	.1432	5.54	2.38	2.23	-.21	+ .04	-16.7	2.83
12987	.921	3.74	.1559	.1431	5.99	2.71	2.56	-.10	- .14	-12.6	2.95
12988	.991	1.10	.2245	.2234	5.36	2.69	2.46	-.01	-1.01	- 7.0	3.17
12989	.987	.46	.2147	.2145	5.72	2.47	2.25	-.19	-1.23	-11.2	2.85
12990	.974	.60	.1796	.1793	5.55	2.30	2.12	+.06	+ .85	-26.7	2.75
12991	1.036	.99	.2437	.2428	5.35	2.50	2.26	-.35	- .69	- 6.7	3.02
13024	1.829	4.40	.2266	.2089	5.41	3.56	3.34	+.20	- .08	-21.2	3.64

(1) Mid-Range Values

(2) $C_{D_o} = C_D - 3\left(\frac{\pi\,\bar{\alpha}}{180}\right)^2$

(3) C.G. is 3.90 calibers aft of nose -- 6-caliber corkscrew

C.G. is 5.16 calibers aft of nose -- 8-caliber corkscrew

Table II. Aeroballistic Characteristics of the 6-Caliber and 8-Caliber Corkscrews

Round	s_g	s_d	$\lambda_F x10^3$ 1/Cal	$\lambda_S x10^3$ 1/Cal	K_F Rad	K_S Rad	ϕ'_F Rad/Cal	ϕ'_S Rad/Cal	Yaw Radius RMS Yaw Fit Fast	Slow	Swerve Radius RMS Swerve Fit Lift	Magnus
6-Caliber Corkscrew												
12491	Short Flight -- Drag Data Only											
12492	3.04	6.84	-.0176	+.0272	.0073	.0064	.0251	.00253	6.1	5.3	5.6	3.0
12493	3.45	.44	-.2450	-.0554	.0104	.0156	.0255	.00218	6.1	9.2	15.5	2.5
12495	4.31	.23	-.2839	-.1630	.0109	.0194	.0255	.00175	9.9	17.6	18.5	.5
8-Caliber Corkscrew												
12986	2.03	.06	-.2104	+.0369	.0182	.0301	.0137	.00285	4.8	7.9	5.7	.03
12987	1.64	.43	-.1393	.0077	.0399	.0511	.0135	.00309	17.3	22.2	10.5	.25
12988	2.02	.89	-.0521	-.0645	.0136	.0135	.0137	.00280	5.7	5.6	2.6	.5
12989	1.66	.10	-.1772	+.0196	.0037	.0070	.0142	.00289	1.3	2.5	1.6	.4
12990	1.71	.44	-.2338	-.0277	.0066	.0079	.0136	.00295	3.0	3.6	1.4	.25
12991	1.78	.53	-.1658	+.0542	.0093	.0145	.0139	.00276	3.9	6.0	3.3	.4
13024	1.93	.92	-.1299	-.1029	.0548	.0533	.0145	.00265	20.3	19.7	42.1	.5

Table III. Physical and Aerodynamic Characteristics

ℓ/d	6	7	8	9	10	11
Vol/r^3	18.0	21.5	24.9	28.4	31.9	35.4
C.G.	3.90	4.53	5.16	5.79	6.43	7.06
$I_y/\rho_m r^5$	91.2	151.2	233.0	339.9	458.9	624.5
k_y	1.13	1.33	1.53	1.73	1.90	2.10
$I_x/\rho_m r^5$	6.48	7.85	9.23	10.60	11.97	13.35
k_x	.300	.302	.304	.305	.306	.307

For Mach Number = 2.1 and Spin = 1/15 cal.

C_{N_α} (estimated)	3.4		3.4		3.2	3.2
C_{M_α} (estimated)	2.58		4.08		5.69	6.28
s_g	3.73		2.27		1.39	1.15

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1. Anders S. Platou, "An Improved Projectile Boattail," Ballistic Research Laboratory Memorandum Report No. 2395, July 1974. AD 785520.

2. Anders S. Platou and George I. T. Nielsen, "An Improved Projectile Boattail. Part II," Ballistic Research Laboratory Report No. 1866, March 1976. AD A024073.

3. Anders S. Platou, "An Improved Projectile Boattail. Part III," Ballistic Research Laboratory Memorandum Report No. 2644, July 1976. AD B012781L.

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6. Anders S. Platou, "Wind Tunnel, Aeroballistic Range, and Full Range Flight Tests of the Non-Conical Boattail Projectile A," Ballistic Research Laboratory Memorandum Report in preparation.

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LIST OF SYMBOLS

C_D — $\dfrac{\text{Drag}}{\frac{1}{2}\,\rho\, V^2\, S}$; positive direction is aft

C_{D_o} — zero angle-of-attack drag coefficient

C.G. — center of gravity, calibers aft of nose

C_{L_α} — $\dfrac{\text{Lift Force}}{\frac{1}{2}\,\rho\, V^2\, S}$; positive direction is up

C_M — $\dfrac{\text{Pitching Moment}}{\frac{1}{2}\,\rho\, V^2\, S\, d}$; positive moment is due to positive normal force ahead of the moment center

C_{M_α} — $\dfrac{d\, C_M}{d\, \alpha}$ at $\alpha = 0$ per radian

C_{M_p} — $\dfrac{\text{Magnus Moment}}{\frac{1}{2}\,\rho\, V^2\, S\, d\, \frac{pd}{V}}$; positive moment is due to positive Magnus force ahead of moment center

$C_{M_{p\alpha}}$ — $\dfrac{d\, C_{M_p}}{d\, \alpha}$ at $\alpha = 0$ per radian

$C_{M_q} + C_{M_{\dot\alpha}}$ — $\dfrac{\text{Damping Moment}}{\frac{1}{2}\,\rho\, V^2\, S\, d\, \frac{|q_t|\, d}{V}}$

C_N — $\dfrac{\text{Normal Force}}{\frac{1}{2}\,\rho\, V^2\, S}$; positive direction is up

C_{N_α} — $\dfrac{d\, C_N}{d\, \alpha}$ at $\alpha = 0$ per radian

C_{N_p} — $\dfrac{\text{Magnus Force}}{\frac{1}{2}\,\rho\, V^2\, S\, \frac{pd}{V}}$; positive direction is to right looking upstream

LIST OF SYMBOLS (Continued)

$C_{N_{p\alpha}}$	$\dfrac{d\,C_{N_p}}{d\,\alpha}$ at $\alpha = 0$ per radian
$C.P._N$	normal force center of pressure
d	projectile diameter
I_x	axial moment of inertia
I_y	transverse moment of inertia
k_x	axial radius of gyration
k_y	transverse radius of gyration
K_F	length of fast arm in epicyclic motion
K_S	length of slow arm in epicyclic motion
m	projectile mass
M	Mach number
p	projectile spin, rad/sec (positive is clockwise looking upstream)
q_t	complex transverse angular velocity
r	projectile radius $= \dfrac{d}{2}$
S	body area $= \dfrac{\pi\, d^2}{4}$
s_d	dynamic stability $= \dfrac{2\,(C_{L_\alpha} + k_x^{-2}\, C_{m_{p\alpha}})}{C_{L_\alpha} - C_D - k_y^{-2}\,(C_{M_q} + C_{M_{\dot\alpha}})}$

s_g	gyroscopic stability = $\dfrac{\left(\dfrac{I_x}{I_y}\right)^2 \left(\dfrac{pd}{V}\right)^2}{4\, \dfrac{\rho S d^3}{2I_y}\, C_{M_\alpha}}$
V	magnitude of the free stream velocity
α	angle of attack
$\overline{\alpha}_t$	mean angle of attack during each flight
δ	cant angle of fin or twisted surface
ρ	free stream air density
ρ_m	projectile mass
λ_F	damping rate of fast arm in epicyclic motion
λ_S	damping rate of slow arm in epicyclic motion
ϕ'_F	rotational rate of fast arm in epicyclic motion
ϕ'_S	rotational rate of slow arm in epicyclic motion

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